HITCHED TO EVERYTHING

PLANT-WATER RELATIONS IN COMMERCIAL CANNABIS CULTIVATION

PLANT-WATER RELATIONS

The celebrated naturalist John Muir once wrote “When we try to pick out anything by itself, we find it hitched to everything else in the Universe.” This is a useful thought for cultivators to keep in mind while optimizing their grow or solving issues with their crops. Many growers use a reductionist approach in their garden, trying to pinpoint a single nutrient or light wavelength to change. While the strategy of isolating and focusing on such very specific parts of the grow is useful for determining the effect of changes to production and finetuning plant growth, we find that in plant biology everything truly is hitched together, and as we dig deeper, we find that everything is hitched together with water.

Water is the basis of everything in cultivation; from plant nutrition, growth and development to environmental controls. An understanding of how water moves through plants and how this movement is influenced by the environment is fundamental to a more holistic and nuanced perspective from which to approach cultivation. When troubleshooting any part of cultivation, water should never be overlooked since each part

of cultivation is inexorably hitched to the wet stuff.

PROPERTIES OF WATER

Water possesses unique qualities that make it a versatile tool, building block and conduit for all living organisms, making it essential for all life on Earth. These qualities are due to water's polar nature, its ability to absorb energy, and its tendency to equalize its solute concentration through diffusion and osmosis. Water is a polar molecule, meaning it has both a negatively and positively charged side, like a magnet. These charges allow water molecules to stick together (a property called cohesion), stick to other materials (a property called adhesion) and dissolve more substances than any other liquid, earning it the moniker "The Universal Solvent". Adhesion and cohesion are both critical to the movement of water through plants. The ability of water to dissolve so many substances make it a natural carrier for all the essential nutrients and energy that sustain plant life.

A RECENT STUDY HAS SHOWN THAT MEDIA WITH MORE DRAINAGE, AND THUS MORE OXYGEN, PRODUCED PLANTS THAT YIELDED MORE DRY FLOWER AND CANNABINOIDS [1]

Polarity also explains the movement of water through media and soil. Media and soil contain pores of various sizes. Generally, following irrigation, water will be pushed down and out of larger pores by the force of gravity. In smaller pores, however, gravity is not powerful enough to overcome the adhesive force binding water to the side of the pore. With this in mind, the proportion of small and large pores dictates the ratio of air (large pores) to water (small pores) after a growing medium is drained. The ability of adhesion and cohesion to overcome gravity also explains how media can pull water up in sub-irrigation systems; as water climbs small pores by adhering to their sides, it pulls more water up behind it with cohesive force. The level of oxygen in soil and water is particularly important for a hungry crop like cannabis. A recent study has shown that media with more drainage, and thus more oxygen, produced plants that yielded more dry flower and cannabinoids [1]

Polarity is also at the heart of water's ability to dissolve so many substances. The polar charge of water can overcome the charge that holds other substances together. The concentration of materials dissolved in water is measured through electrical conductivity (EC) and the concentration of charged hydrogen atoms, or protons, in water is expressed as pH. Together, pH and EC are some of most important parameters for cultivators to consider as they, to a large degree, dictate the concentration and availability of nutrients in water.

The cellular machinery of plants performs a wide variety of biochemical reactions to facilitate growth and development. These reactions are regulated, in large part, by temperature. Unlike animals and other mobile organisms, plants are unable to move out of unfavorable environments and instead must adapt. Because plants are made up of about 90% water, the slow rate at which water heats and cools provides an excellent buffer for plants from temperature fluctuations in the environment. Water has the highest "specific heat" value of any substance commonly found on earth, meaning it takes more energy to raise a gram of water by 1°. The high specific heat of water

guards plants against rapid changes in air temperature.

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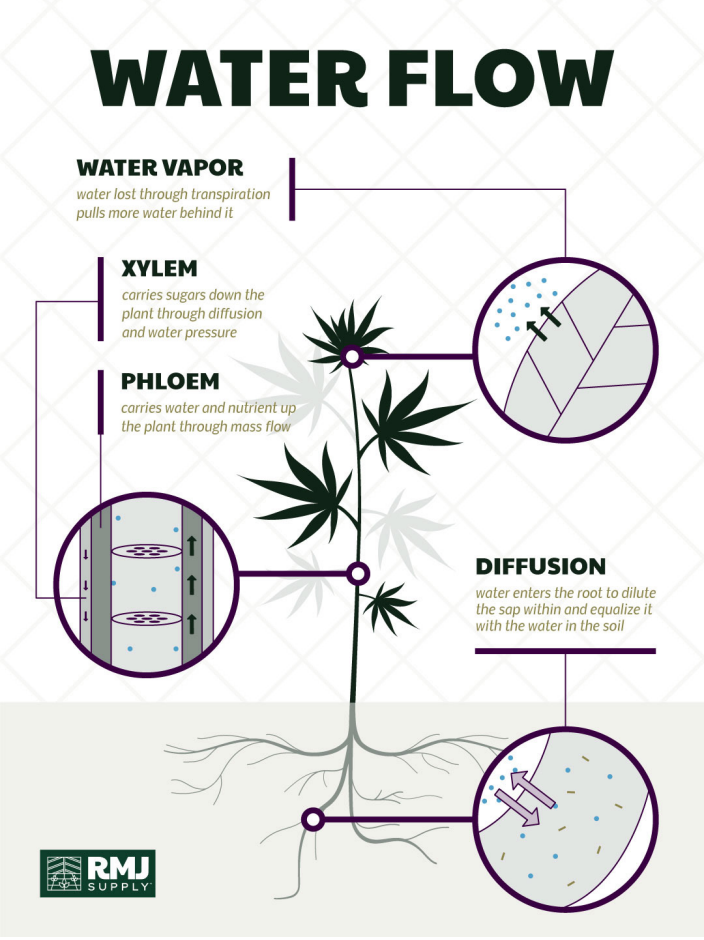
Water, by virtue of its ability to absorb energy, is also one of the key players in photosynthesis. Along with absorbing heat, water in plants absorbs and converts light energy to power photosynthesis. When light hits a leaf, the energy splits water molecules into oxygen and charged protons. These protons are the power source for the next steps of photosynthesis which make energy in the form of carbohydrates.

Water tends to equalize the concentration of solutes within it, meaning water with a lower concentration of solutes tends to flow toward water with a higher concentration of solutes until there is an even concentration of solutes throughout. This action is called diffusion and often takes some time to occur. This is important to keep in mind when flushing a root zone, either to collect runoff samples or to leach excess salts. Applying a large volume of water with a lot of runoff is less effective than applying just enough water to saturate the media, leaving it for an hour to allow salts to diffuse before applying a second dose of water [2]. When diffusion happens across membranes, such as those found between cells, it is called osmosis. As we will see, osmosis plays a key role in moving resources to where they are needed within plants.

MOVEMENT OF WATER THROUGH PLANTS

Cohesive and adhesive forces are at the foundation of how water moves through plants. This "mass flow" of water through cohesion and adhesion works as a conveyer belt to transport nutrients and energy throughout plants.

The main conduits of water through plants are the vascular tissues of the xylem and phloem: tiny tubes that run the length of the stem and branch to all other parts of the plant. In the xylem, water carries nutrients from the root zone to the top of the plant. In the phloem, water shuttles sugars from the leaves where they are produced to where they are stored and consumed. Water moves through these vessels using capillary action driven by adhesion to their inner walls and



cohesion between water molecules.
This pulling reaction begins when water in a leaf is warmed by light from the sun or grow lights, causing water within the leaf to exit as water vapor via tiny openings on the leaf surface called stomata (singular stoma). The action of water vapor leaving leaves is called transpiration and is the main driving force of water though plants. Transpiration serves two purposes: cooling the leaf by diffusing light energy into the conversion of liquid water to vapor and driving the movement of water though the whole plant. When water leaves the leaf as water vapor, more liquid water from deeper in the leaf moves closer to the stomata to fill in the empty space, and, in turn, those water molecules pull more water from the xylem causing a chain reaction which ultimately pulls water from soil into plant roots.

The movement of water through plants is tied to the moisture in the environment and soil surrounding plants. Moisture in the air is typically measured as relative humidity (RH); the percentage of the maximum moisture that can be held by air at a given temperature. Warmer air can hold more moisture than colder air. Temperature along with RH can be used to calculate vapor pressure deficit (VPD), essentially the pressure needed to vaporize water. The VPD is important because it is the most significant factor affecting transpiration rate. In the soil, water is pulled into roots through cohesion but it also seeps in through diffusion. The water inside plants often has more material dissolved in it than the water in the soil. Because water tends to equalize solute concentrations through diffusion, water will enter the root to dilute the sap within and equalize it with the water in the soil. Cohesive mass flow combined with diffusion of water into roots creates "root pressure" which also works to push water up the plant.

Often, under dry conditions, not enough water is pulled up the stem to keep pace with transpiration, so there is more water leaving the plant through transpiration than is being replaced, leading to drought stress. With a lack of water, the pressure within leaves and stems drops, causing the plant to wilt. Given enough drought stress, leaves will dry out and the plant will die.

Plants can regulate transpiration to an extent by opening and closing stomata but there are times when transpiration is either too fast or too slow to balance water being drawn up the stem. Transpiration rate is especially important when rooting clones. Before roots have developed, the clones have no way of taking up more water so transpiration must be limited as much as possible. This is often achieved by cutting or "docking" leaves. However, since leaves contribute carbohydrates and natural rooting hormones, a preferable approach is raising relative humidity to close to 100% [3]. Once roots begin to develop, humidity must be gradually lowered to encourage transpiration and limit mold risk.

Conversely, drought stress also prompts a stress response throughout the plant that could benefit cannabis cultivation in two ways. One part of the stress response is to devote more resources to reproduction, or flowers. Another stress response is to increase defensive compounds such as cannabinoids and terpenes. Indeed, a recent study has shown mild drought stress during the last two weeks of flower can significantly increase cannabinoid production and flower dry weight [4]

Excess water can be just as damaging as too little water. oxygen is essential for roots to grow and function. If there is too much water

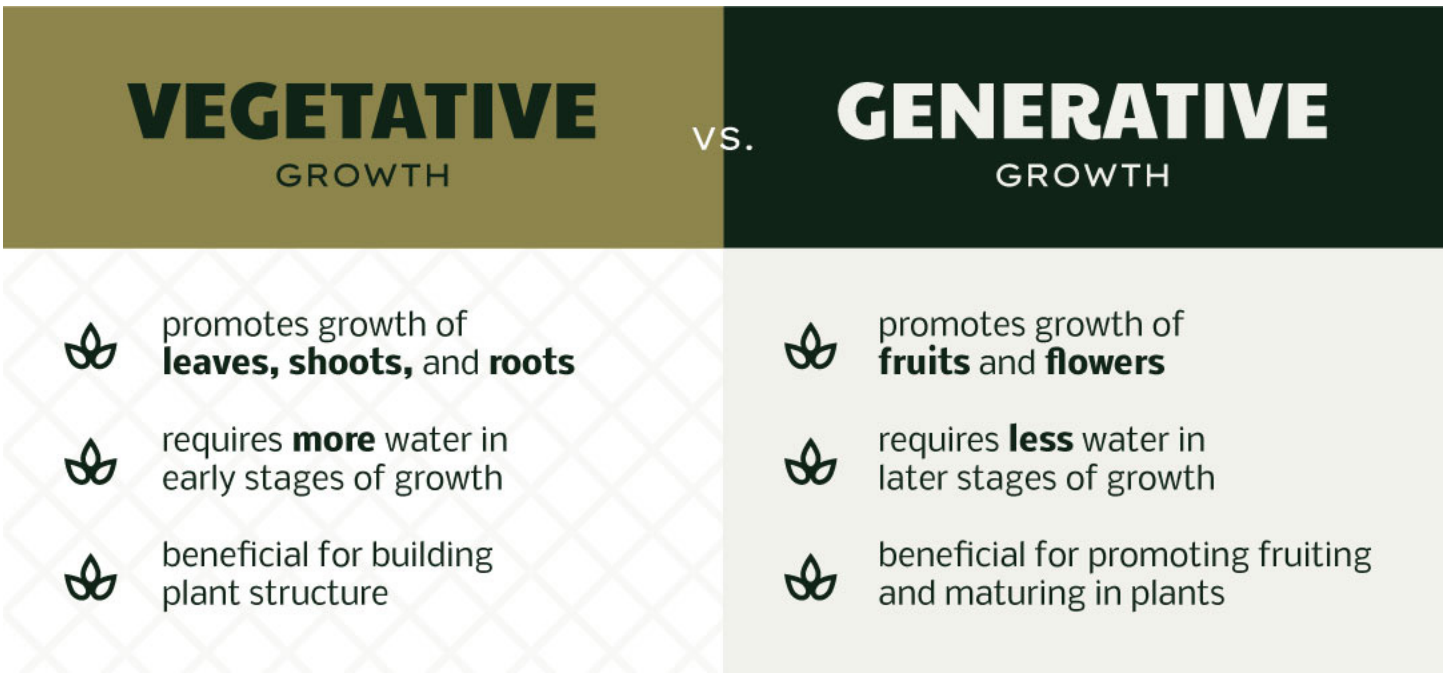
in the soil, roots are suffocated and die. A waterlogged environment also promotes the proliferation of various plant pathogens and pests.

Irrigation strategies have long been used as a no-cost method of controlling crop growth and development. Beginning with greenhouse tomatoes, growers discovered that shifting certain growing parameters one way or the other would promote either vegetative (leaves, shoots, roots) or generative (fruits and flowers) growth. It is now common practice to adjust irrigation strategies to drive vegetative growth to build plant structure, and gradually shift to a generative irrigation strategy to promote fruiting and maturing. This technique can be similarly used to steer cannabis toward vegetative or generative growth. Providing more water earlier in the crop cycle and less water later can promote vegetative growth earlier and generative growth later.

Under some conditions, the pull of water at growing points can outpace their need for water, leading to excess water pressure within the plant. This excess pressure can be released via a controlled process called guttation, or an uncontrolled process called edema. Guttation releases the water pressure by expelling water drops through xylem outlets on leaf margins. Edema occurs when water pressure causes cells to burst. Fluids on foliage is not ideal in any case as it can lead to microbial growth and infections, but at least guttation is a controlled process with some safeguards against pathogens. Edema, on the other hand, leaves vulnerable, damaged cells and nutrient rich sap exposed to infection [5].

MOVEMENT OF NUTRIENTS AND ENERGY THROUGH PLANTS

There are 18 nutrient elements required by plants and most of them are absorbed as charged particles called ions. Most nutrients are absorbed as positively charged cations and some as negatively charged anions. In the absence of water, most essential nutrients exist as salts; a solid combination of cations and anions joined together by their complimentary charges. As the "Universal Solvent" the polarity of water molecules overcome the charge between the ions in a salt, dissolving it and putting the ions



	VEGETATIVE	GENERATIVE
Temperature/Humidity	↑	↓
Day/Night Temperature/Humidity Change	↑	↓
Irrigation Volume and Frequency	↑	↓
Root Zone EC	↓	↑
Nitrogen	↑	↓
Calcium and Potassium	↓	↑

in solution. This soil solution comprised of water, dissolved salts, and organic compounds is what plant roots absorb.

WITH THIS UNDERSTANDING, ONE CAN DEMYSTIFY THE BELIEF THAT DIFFERENT FERTILIZER BRANDS MAKE SUPERIOR OR INFERIOR NUTRIENTS. THE NUTRIENTS ARE THE SAME IN ALL FERTILIZERS

Once nutrient ions are absorbed, the travel up the plant in the xylem. Some nutrients are mobile, meaning they can be transported to where they are needed in the plant. Others are immobile, meaning they are irreversibly knit into the structure of the plant and cannot be relocated. Some nutrients move more readily through mass flow and other through concentration differentials. Nutrients that require more mass flow for transport, like calcium, need plants to transpire steadily to avoid deficiencies. In fact, calcium is frequently supplied in sufficient quantities, but a lack of transpirations leads to a deficiency.

Because all mineral nutrients are absorbed in the same ionic forms, there is not much room for variation in fertilizers beyond ratios of the nutrients. There are certainly compounds beyond the essential 18 that can benefit plant growth and improved ways of delivering nutrients. A recent study has shown an organic supplement (humic acid) produces plants with more evenly distributed cannabinoids throughout a cannabis plant [6]. However, the main differences between most fertilizers is the ratios of essential nutrients. With this understanding, one can demystify the belief that different fertilizer brands make superior or inferior nutrients. The nutrients are the same (organics are a little more complicated) in all fertilizers. Beyond transporting nutrients, water chemistry influences nutrient availability. Water pH can have dramatic effects on

the availability of nutrients so pH must be maintained within a specific range depending on growing medium. Also important, is the ratio of nutrients. Many nutrients have complex synergistic or antagonistic effects on other nutrients, so the overall chemical balance of irrigation water is very important to plant nutrition.

Like with nutrients, plants transport energy to where it is needed using water. All the energy plants use to grow and develop is solar energy. Plants capture solar radiation with their leaves (sources) and convert it into biologically available energy stores in the form of sugar. Sugars are then transported to parts of the plant that require more energy (sinks), like actively growing shoot and root tips, flowers, fruits and seeds. Osmosis plays a big role in the transport of sugars from sources to sinks. Closer to the source, sugars are pumped into the phloem to create a higher concentration of solute in the phloem sap. To balance the concentration gradient, water from the xylem will flow into the sugary phloem, raising the pressure in the phloem and pushing the phloem sap toward sinks. Sugar is also pulled by osmosis to the sink because sugars are being consumed, lowering the sugar concentration closer to the sink.

CONCLUSION

After this condensed tour of plant-water relations in cannabis, we can now see how water drives all the important processes in plants and how we find ourselves hitched to water when considering anything in cultivation from fertilizers to cloning. Armed with an understanding of the mechanics of how water moves in the rootzone, plant and atmosphere, and how it moves all the materials plants need, we hope you will find a more holistic prospective from which to approach crop management.

KEY TAKEAWAYS

The properties of water, such as its polarity, specific heat, and status as the “Universal Solvent” make it uniquely well suited to support life. These properties are important to consider when designing, managing, or troubleshooting a cultivation system.

Movement of water through plants is the basis for movement of nutrients and energy in the plant too, so growers can drive growth and development by managing transpiration through the environment.

Water is connected to all aspects of cultivation so being able to control the water status of the root zone through irrigation, and the humidity of the air through environmental controls is essential to managing cultivation holistically.

ABOUT THE AUTHOR

Jack Lamont is a horticulturist, plant scientist, commercial cannabis grower. He is on a mission to stamp out myths and misconceptions in cannabis cultivation using established plant science and emerging cannabis research. With more than a decade of experience in horticulture, he has led cultivation departments of cannabis production facilities in Canada and The United States. He has also authored numerous scientific and trade journal articles, served on various scientific committees, and recently founded a biodynamic vegetable, herb, and poultry farm with his family in Keene, New Hampshire.

REFERENCES

[1] Caplan, D., Dixon, M., & Zheng, Y. (2017). Optimal rate of organic fertilizer during the flowering stage for cannabis grown in two coir-based substrates. HortScience, 52(12), 1796-1803.

[2] Cavins, T. J., Whipker, B. E., & Fonteno, W. C. (2005, September). Pourthru: A method for monitoring nutrition in the greenhouse. In International Symposium on Growing Media 779 (pp. 289-298).

[3] Caplan, D., Stemeroff, J., Dixon, M., & Zheng, Y. (2018). Vegetative propagation of cannabis by stem cuttings: effects of leaf number, cutting position, rooting hormone, and leaf tip removal. Canadian Journal of Plant Science, 98(5), 1126-1132.

[4] Caplan, D., Dixon, M., & Zheng, Y. (2019). Increasing inflorescence dry weight and cannabinoid content in medical cannabis using controlled drought stress. HortScience, 54(5), 964-969.

[5] Madeiras, A. (2019) Edema and intumescence. UMass Extension Fact Sheet, https://ag.umass.edu/greenhouse-floriculture/fact-sheets/edema-intumescence

[6] Bernstein, N., Gorelick, J., Zerahia, R., & Koch, S. (2019). Impact of N, P, K, and humic acid supplementation on the chemical profile of medical cannabis (Cannabis sativa L). Frontiers in plant science, 10, 736.

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